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QUARTERLY PROGRESS REPORT

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Bellcomm

QUARTERLY PROGRESS REPORT

April May June

1970

I. M. Ross
President

Bellcomm
955 L'Enfant Plaza North, S. W. Washington, D. C. 20024

Report No. 70-101-3
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QUARTERLY PROGRESS REPORT

ABSTRACT

The activities of Bellcomm during the quarter ending June 30, 1970 are summarized. Reference is made to reports and memoranda issued during this period covering particular technical studies.

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MISSION PLANNING

Mission Assignments

Prior to the flight of Apollo 13, changes in mission requirements which had arisen subsequent to the January 1970 issue of the Apollo Flight Mission Assignments appendix were outlined for the Associate Administrator.

The draft of the complete Apollo Flight Mission Assignments document was revised to include a new format for velocity requirements, scientific rationales for candidate landing sites, and primary objectives revised to complement the scientific rationales. Issue of the document awaits a resolution of flight assignments subsequent to the Apollo 14 mission.

Technical activities related to Apollo 13 and Apollo 14 included final review of the rules for lunar surface operations including Apollo Lunar Surface Experiments Package (ALSEP) rules for Apollo 13, participation in the Apollo 13 postflight debriefings, and a review of the initial issue of the Apollo 14 Mission Implementation Plan.

Space Vehicle Performance

Preparation and delivery of the Quarterly Weight and Performance Report, as well as presentation of weight and performance status at the regular Apollo Program Office Reviews, continued. At the request of the Apollo Program Director, a new format for presenting weight and performance data was developed. The revised format emphasizes payload commitments and available performance margins providing a better basis for decisions relating to improved scientific returns. Current data in this format have also been prepared and submitted to the Apollo Program Director as requested to support decisions regarding experiment assignments.

A presentation to the Apollo Program Director of May 28 included a review of ΔV budgets, propellant budgets and limit weight computations for the Lunar Module (LM) ascent propulsion system, descent propulsion system, and Service Module (SM) propulsion system. The LM status of nominal budgets and dispersions was covered as well as the sensitivity to change of the various elements in the budgets.

Work was done to revise the space vehicle control weight and performance parameters. On June 12 the Apollo Program Director reviewed the launch vehicle and spacecraft weight and performance status with project management from MSC and MSFC, and approved recommended revisions to the control weights for both the H-series and J-series missions.

The effects of premature S-II center engine cutoff on the Saturn V payload capability were evaluated.[1] In the extreme case of failure of the S-II center engine to ignite, the payload penalty would be about 9,100 pounds. In a related study, it was determined that removal of the S-II center engine would result in a payload penalty of about 7,500 pounds.

Apollo 13 post-flight launch vehicle data were analyzed for end-of-mission propellant reserves.[2] It was found that the amount of usable S-IVB propellant remaining after translunar injection was equivalent to the required (pre-flight) flight performance reserve plus one to five seconds of additional burn time, depending on the method used for the calculation. This was consistent with the real-time prediction made by MSFC after parking orbit insertion.

An analysis of the effect of lunar slopes on LM descent guidance was made.[3] It was shown that when no a priori correction for the expected terrain is made, a slope corresponds approximately to a misalignment of axes, which in turn can result in large LM guidance perturbations. The analytical techniques developed should provide a useful adjunct to detailed simulations, including the evaluation of recent modifications to the guidance scheme which use an expected terrain profile.

Mission Analysis

Opportunities for missions to the candidate J-mission sites have been determined for the period through 1974.[4]

A study of lunar surface area accessible for the period November-December 1971 was completed. This study was prompted by the lack of lunar landing sites suitable for J-missions in the winter months. The results define the particular southeastern portion of the near side of the moon, including a large portion of the southern highlands which will be accessible in this time period.

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(1) Payload Effect of Premature S-II Center Engine Cutoff, Memorandum for File, K. P. Klaasen, June 8, 1970.

(2) Summary of Apollo 13 Launch Vehicle Propellant Reserves, Memorandum for File, K. P. Klaasen, June 24, 1970.

(3) Effect of Lunar Slopes on LM Guidance Perturbations Prior to High Gate, P. Gunther, TM-70-1033-4, April 16, 1970.

(4) Feasibility of Hybrid Lunar Missions to Hadley, Copernicus, Davy, Marius Hills and Descartes from Early 1971 through 1974, Memorandum for File, D. R. Anselmo, R. A. Bass, June 2, 1970.

The 210-foot antenna coverage for an Apollo 14 mission in December 1970 and January 1971 was determined.[5] It was found that powered descent initiation (PDI) would be visible from the Goldstone antenna for the December launch, but that neither Goldstone nor Parkes could view PDI for a January 2, 1971 launch.

A study was completed to determine the effect of Service Module propellant loading on the probability of mission success.[6] The study showed that there is an optimal propellant loading which in many cases is less than full tanks. It was also shown that a strategy of using the spacecraft propulsion to back up the S-IVB for completion of translunar injection can permit a launch with full SPS tanks in cases where the launch vehicle payload capability would not normally permit full SPS tanks.

The mission analysis optimization capability of the Bellcomm Apollo Simulation Program (BCMASP) was extended to include full optimization of earth-return ΔV costs for lunar exploration missions with high inclination lunar parking orbits.[7] With this capability, the time available for lunar orbital science can be related to the transearth flight time and to the earth landing location.

Comparative evaluations were made of scientific returns from H- and J-mission systems, and from the Apollo 18 and 19 missions versus all preceding missions. These evaluations, prepared for use by NASA in program re-assessments, showed that the increased surface staytime and mobility afforded by J-mission hardware yielded a significant increase in science return over H-type missions. An evaluation was also made of a lunar orbital mission for Apollo 19, considering four different spacecraft configurations.

Guidance and Navigation

Work on the Delta Guidance scheme for LM descent was documented and sent to MSC, noting its potential fuel saving advantages.[8] Suspected instability

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(5) Apollo 14 210-Foot Antenna Coverage for a Fra Mauro Mission in December 1970 and January 1971, Memorandum for File, D. R. Anselmo, May 19, 1970.

(6) A Determination of Optimum SPS Propellant Offloading Including Consideration of Spacecraft Completion of Translunar Injection, TM-70-2013-4, R. J. Stern, June 22, 1970.

(7) An Improved Determination of Optimal Moon-to-Earth Trajectories for BCMASP, Memorandum for File, M. R. Kerr, R. J. Stern, April 20, 1970.

(8) The Use of Delta Guidance for Improved Trajectory Control and Fuel Cost During LM Descent, TM-70-2014-6, J. A. Sorensen, June 11, 1970.

of the throttle control near touchdown was analyzed and changes recommended.[9] These changes are being considered for Apollo 14 and subsequent missions.

The Bellcomm Orbit Determination Program is being applied as a "filter" which yields secular effects of lunar gravity.[10] Lunar Orbiter as well as Apollo data are being processed, the ultimate aim being to determine gravity coefficients.

A predictive guidance scheme, which was developed at the Bell Telephone Laboratories, was reviewed for its applicability to spacecraft guidance during atmospheric entry. Discussions were held with personnel at Ames Research Center concerning the feasibility of the scheme for future space flight programs.

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(9) <u>Linear Stability Analysis of LM Rate-of-Descent Guidance Equations</u>, Memorandum for File, J. A. Sorensen, June 25, 1970.

(10) <u>Orbit Determination for Lunar Parking Orbits Using Time-Varying Orbital Elements</u>, TR-70-310-2, M. V. Bullock, A. J. Ferrari, May 7, 1970.

Apollo Program Specification

Specification Change Notices for Revision B of the Apollo Program Specification (which covers the H-series missions) were prepared, approved and distributed.

The initial issue of Revision C of the Apollo Program Specification, dated April 1, 1970, and covering the J-series missions, was distributed.

Communication Systems

A computer model for path loss of a radio link on a rough spherical surface such as the moon was devised.(11) The model covers the three important regions which depend on the proximity of the receiving antenna to the transmitting antenna, (a) the diffuse reflection region near the transmitter, (b) a specular reflection region beyond (a) to the horizon of the transmitting antenna and (c) a diffraction region - near the horizon and beyond. The expected performance of VHF communication links on the lunar surface was analyzed using measured characteristics of lunar surface material.(12) The path loss was found to be no more than 2dB greater than would be obtained for an equal length path on the earth's surface. The path loss is not sensitive to moderate deviations from the soil parameters assumed.

It is planned that the lunar orbital science package on later Apollo missions will include a subsatellite, which will be released in lunar orbit and used for measurement of the solar wind, the earth's magnetosphere and the gravitational field of the moon. A tracking and data link will be provided between the subsatellite and the Manned Space Flight Network (MSFN). An analysis was made of the performance of the subsatellite-MSFN link.(13) It was found that although the original intent was to support the subsatellite by MSFN stations with 85-ft diameter antennas, stations with 30-ft diameter antennas could provide adequate

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(11) Path Loss Expressions for a Radio Link on a Rough Spherical Surface, TM-70-2034-5, N. W. Schroeder, June 30, 1970.

(12) Path Loss for a Communication Link on the Lunar Surface, Memorandum for File, N. W. Schroeder, June 1, 1970.

(13) Expected Communication Performance of the Apollo Subsatellite, Memorandum for File, R. L. Selden, May 18, 1970.

support if the station and subsatellite performance is nominal. A detailed description and status of the subsatellite design was prepared.(14)

The analysis of phase demodulators appropriate for unified S-band type signals was extended to derive optimum demodulators for operation in the presence of overlapping subcarrier signals.(15) This situation exists in the system used to transmit Apollo color television from the moon.

Lunar Surface Operational Capabilities

An analysis was made of the capability to perform the surface exploration missions planned for Apollo 13.(16) The results indicated that ability to perform the traverse to the distant and primary objectives at Cone Crater on the second Extravehicular Activity (EVA) was marginal.

The important determinants were the uncertainties in both the pre-mission predictions and in the knowledge during the mission of the actual values of (a) space suit leakage rates for oxygen and heat and (b) metabolic rates of the astronauts while performing the relatively strenuous tasks of ascending and exploring the slopes of Cone Crater. These findings were provided to NASA with a recommendation that an option to delete intermediate objectives and proceed directly to Cone Crater be pre-planned for real-time decision if indicated by crew safety and mission success considerations.

After the Apollo 13 mission, a timeline analysis was made to determine the impact on the already planned Apollo 14 surface mission of adding the Apollo 13 scientific instrumentation to the Apollo 14 mission. It was shown the nominal time available for field geology on Apollo 13 would be reduced from three hours and thirty minutes to one hour and forty-five minutes (or less depending on consumables usage rates) if all the experiments scheduled for both missions were flown on Apollo 14. This information was made available to support the decision not to include the heat flow and core drill experiments on Apollo 14.

Studies and analyses to develop operational capability envelopes have continued as well as efforts to promote the development within NASA of Reference Surface Missions for lunar exploration. The constraints resulting from a 66-hour lunar surface stay with one 6-hour and two 7-hour EVAs as well as three

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(14) Description and Status of the Design of the Particles and Fields Subsatellite, Memorandum for File, A. G. Weygand, June 15, 1970.

(15) The Optimum Phase Demodulator for the Interfering PM Subcarrier Signals, TM-70-2034-4, W. D. Wynn, June 3, 1970.

(16) An Analysis of the Capability to Perform the Apollo 13 Fra Mauro Traverses, Memorandum for File, T. A. Bottomley, April 6, 1970.

8-hour rest periods were determined. These were combined with projected -7 Portable Life Support System (PLSS) and Buddy Secondary Life Support System (B/SLSS) capabilities to further define limits for traverse planning.[17] Traverse durations were constrained to a maximum of about five and one-half hours by time and consumables limitations. It was also shown that the maximum return distance for an emergency return to the LM is constrained by the B/SLSS when riding on the Rover and by the PLSS when walking. Activities in conjunction with NASA and the United States Geological Survey (USGS) to create a set of Reference Surface Missions at Marius Hills and Copernicus Peaks are continuing and have reached the point where a set of missions has been developed that match both exploration objectives and current assessments of operational capability.

A modular approach was developed for the definition of sampling station activities during riding traverses.[18] Using simulation data, the results of Apollo 11 and Apollo 12 experience, and current flight planning estimates, times were determined for overhead and engineering tasks at a grab sample station (no Rover egress), a short stop station (no television), and a long stop station (television and scientific instrumentation). These task times can be combined with the scientific activities appropriate to a specific traverse station to provide total sampling station times for use in traverse design tradeoffs. Total station times varied from a low of three minutes for a grab sample station to a half hour or more for a long stop station.

Efforts were initiated to assist NASA in the development of a set of guidelines (constraints, capability envelopes, etc.) for lunar surface mission planning in the Apollo Program. Preliminary guidelines relating consumables usage for combinations of riding and non-riding exploration activities have been established for the life support systems.[19]

Lunar Roving Vehicle Studies

A computer program for determining the dynamic stability of the Lunar Roving Vehicle (LRV) was furnished to the MSFC at their request, and its use was discussed with Center personnel. A preliminary dynamic stability study of the LRV was made. A joint effort with MSFC is in progress to extend the analysis using updated suspension and geometric properties of the vehicle.

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(17) Revision of Operational Constraints for J-Mission Traverse Planning, Memorandum for File, P. Benjamin, April 7, 1970.

(18) Projected Activities at Science Station for J-Mission Traverse Planning, Memorandum for File, P. Benjamin, April 1, 1970.

(19) -7 PLSS Capability Using Current MSC Data and Assumptions, Memorandum for File, P. Benjamin, June 29, 1970.

The proposed design of the LRV navigation system was reviewed, and it was found that with the allowable gyro drift rate realignment was necessary at intervals as short as 15 minutes. It was concluded that tighter limits were readily achievable, and should be specified to reduce the operational overhead costs of LRV navigation.

Crew Performance Studies

To determine limitations of crew performance during an EVA, a study was made of the influences on human fatigue of workload, sleep deprivation and heat stress.[20] It was found that the onset of fatigue will occur after about five hours and the end point for useful work will occur after about eight hours. It was proposed that the five-hour limit be used during pre-mission planning to be extended to the eight hour limit in real time to accomplish important objectives if permitted by crew condition and future planned activities. Work/sleep guidelines were suggested for nominal and emergency modes of operation to minimize the effect of sleep deprivation on fatigue.

A review of the medical experiments proposed for the J-missions was performed with emphasis upon the impact of the experiments on missions operations.[21] Four of the six experiments are already being carried out informally to various degrees, and their formal implementation would have only a small additional impact upon the missions. The return of the lithium hydroxide canister used for CO_2 removal on the lunar surface and the measurement of residual feed water in the life support system used on the lunar surface were found to have merit. It was felt these data would help in determining metabolic rates on the lunar surface but that the associated ground test program should be implemented in advance independent of whether the proposed flight missions experiment is approved. These recommendations were made in a presentation to the Apollo Mission Director on May 21.

Launch Systems

An analysis of the operational constraints resulting from common use of the launch facilities at KSC by both Apollo and Skylab was made to determine the feasibility of interleaving Apollo and Skylab missions. It was found that the Mobile Service Structure was the critical facility and that Apollo launches

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(20) Crew Fatigue Limits for Apollo Operations, TM-70-2032-1, T. A. Bottomley, June 30, 1970.

(21) Proposed Medical Experiments for the J-Missions, Memorandum for File, P. Benjamin, June 11, 1970.

would not be possible during the period from three months before to nine months after the launch of Skylab I.[22]

Space Vehicle Systems

S-II POGO modeling and stability analyses were continued following the S-II center engine oscillation and shutdown on the Apollo 13 mission. Spectrograms of selected acceleration and pressure measurements from several flights were made and discussed with the POGO Working Group at the Marshall Space Flight Center. These established that the S-II LOX line resonance in flight is 25 Hz, and provided increased insight into S-II and S-IVB structural modes.[23,24] A hypothesis which explains certain subtle features of S-II POGO was developed and a computer simulation incorporating a non-linear cavitation compliance has been initiated in an effort to check the hypothesis.[25] Analyses support the use of an accumulator in the center engine LOX line for POGO suppression, and indicate that stability during the accumulator fill sequence is the principal remaining uncertainty.

A method has been developed for analyzing the response of linear systems containing feedback loops which are subjected to nonstationary statistical excitation. The systems can be time varying and can consist of structures, control elements and other subsystems. The method uses the state variable techniques primarily attributed to Kalman, and hence gives a time domain analysis.[26]

A method for obtaining the eigenvalues and eigenvectors of a nonsymmetric real matrix has been developed.[27] A program is available in the Fortran V language. All eigenvectors of a repeated root are obtained in orthonormalized

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(22) Skylab and Apollo Launch Constraints, Memorandum for File, A. W. Starkey, June 3, 1970.

(23) Contour Spectrograms for POGO Analysis, Memorandum for File, A. T. Ackerman, L. A. Ferrara, J. J. O'Connor, April 10, 1970.

(24) Spectrograms of SA-508 POGO, Memorandum for File, A. T. Ackerman, L. A. Ferrara, J. J. O'Connor, May 25, 1970.

(25) A Theory of S-II POGO, Memorandum for File, J. J. O'Connor, May 14, 1970.

(26) Statistical Analysis of Nonstationary Structural Response Under Feedback Conditions, TM-70-2031-2, I. Y. Bar-Itzhack, S. N. Hou, April 6, 1970.

(27) The Complete Eigenvalue Problem for General Real Matrices, TM-70-1033-7, V. Thuraisamy, June 16, 1970.

form; the defects of defective matrices are detected and all independent eigen-vectors are extracted. The impetus for the method arose from analyses of complex structural problems.

Several studies relating to cryogenic storage systems were undertaken as a result of the Apollo 13 oxygen tank failure. A comparative study was made of the alternatives available for stowing the consumables required by the CSM environmental control and electrical power systems. Based on weight and volume considerations, sub-critical, liquid oxygen stowage would become an attractive alternative if use of the current super-critical stowage system could not be continued.

Work was done to develop quantitative analytical understanding of the physics applicable to the Apollo cryogenic oxygen system, and to compare the theoretical behavior with flight data. This included consideration of heat transfer mechanisms and energy interchanges during tank operation. An interim review was held for the Apollo Program Director on June 5.

The capability of the CSM cryogenic storage system to support an orbit-only lunar mission was assessed for several spacecraft and orbital science configurations. It was found that, similar to landing missions, hydrogen is the limiting consumable, and mission durations would probably be limited to 14 days.

APOLLO/SATURN SYSTEMS ENGINEERING
SCIENTIFIC STUDIES

Site Selection

A review of scientific objectives for the Davy, Censorinus and Littrow sites was presented to the Group for Lunar Exploration Planning (GLEP) on April 30, with emphasis on the need to visit a highland site as early as possible.

Potential landing sites for the Apollo 15 and Apollo 16 missions were identified, and their characteristics and scientific objectives were presented to the Site Selection Subgroup of GLEP on June 5. The capabilities for traverses on foot at Marius Hills and Copernicus Peaks on Apollo 15 and 16 were also studied and presented to the subgroup. Minutes of the meeting were prepared and issued.(28)

Apollo 12 photography of the Descartes area was studied to determine areas of scientific interest. Two points within walking distance from a crater chain and a young impact crater were selected as potential landing sites. They are being studied by MSC for terrain smoothness and for adequacy of photographic coverage for Apollo 15.

A new candidate landing site, Ladé C located at 14° east longitude and 1° south latitude, was analyzed as a possible highland backup site.

A presentation on Apollo site selection and science planning was given to the Lunar and Planetary Missions Board and to the Science and Technology Advisory Committee. The rationale for site selection was developed, and the interrelationships between the sites were identified.

Apollo 12

Post-mission study of the Apollo 12 mission continued with a publication summarizing the geology of landing site 7 and the scientific objectives of the mission.(29) Analysis of the Apollo 12 traverse design characteristics and results continued.

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(28) Minutes of the GLEP Site Selection Subgroup Meeting - June 6, 1970, Memorandum for File, F. El-Baz, June 10, 1970.

(29) Apollo 12 - Landing Site 7 - Part 1; Geology of the Landing Site and Scientific Objectives, Memorandum for File, J. W. Head, April 13, 1970.

Apollo 13

Bellcomm participated in a crew review of the Apollo 13 photographic flight plan on April 2 and 3, and in a revision to the plan following the replacement of the Command Module Pilot. During the mission, assistance was provided in planning photography of the damaged area of the Service Module.

A photograph of the oxygen cloud formed in the Apollo 13 accident, taken by the Mount Kobau National Observatory in British Columbia, was scanned and encoded with the aid of a microdensitometer system located at Howard University. The encoded data points were transformed to point exposure/ background exposure ratios and selected areas were then integrated on the Bellcomm computer. These data are being used in an analysis of the mass, shape, and diffusion rate of the cloud.

The seismogram resulting from the Apollo 13 S-IVB lunar impact has been analyzed by the experiment team and the most significant conclusion is that no major discontinuity exists shallower than 20 km. The results of the study have been submitted to Science for publication. Bellcomm's participation as a member of the seismic experiment team will be concluded with the publication of this article.

Apollo 14

A geological study of the Fra Mauro landing site has been updated and referenced to the objectives of the Apollo 14 mission.

The Apollo 14 prime and backup crews were briefed on lunar science terminology and the objectives of orbital science and photography. Emphasis was placed on the importance of landing site photography to the lunar exploration program.

A preliminary photographic plan for Apollo 14 was prepared and accepted by the flight planners. The plan was subsequently revised following the MSC decision to carry only three film magazines for the Hycon camera.

Bellcomm, with the cooperation of the United States Geological Survey, arranged a briefing for the Apollo 14 Command Module Pilots. The objectives of orbital observations and photography were discussed inflight over an area in Arizona which included terrain analogous to lunar surface features.

Lunar Surface Science

A review was conducted of an apparent "gas event" detected by the Apollo 12 Suprathermal Ion Detector at the time of the Apollo 13 S-IVB impact. Data from the Apollo 12 LM liftoff and LM impact were also included in this review. It was concluded that the data cannot be directly accounted for by released gas. A complicated intermediary solar wind collision-ionization process must be operative (perhaps in three forms). A simple, unique and credible data analysis is therefore not likely.

A study was completed on the candidate experiments for the J-missions and their relationship to the surface timelines and to the astronauts' other operational and scientific activities.(30) The study was based on the experiment objectives and the nature of the phenomena to be investigated rather than on hardware details that would be subject to change. The study concluded that objectives of the Portable Magnetometer and Far UV/Lyman Alpha Experiments will have to be restricted due to the limited surface stay time and that the Surface Electrical Properties Experiment poses some severe constraints on the EVAs, especially if it requires a walking traverse. The results of this study were presented to the Lunar Surface Operations Planning Meeting on June 26, 1970.

A study was completed on the shape of rays from lunar craters.(31) It was found that the position and shape of a ray pattern may be related to the depth from which the ray material originated.

The electrostatic potential of the Lunar Communications Relay Unit S-band antenna was investigated because of a suggested possibility that the antenna could charge up to a potential of about a thousand volts. It was found that the operating potential will not differ much from its non-operating value which is expected to lie in the range of one to ten volts while the Rover is on the sunlit hemisphere.

The Moon as Viewed by Lunar Orbiter by L. J. Kosofsky of NASA and F. El-Baz of Bellcomm was issued during this quarter as a NASA Special Publication.(32) The volume provides nearly complete coverage of the lunar surface at medium resolution and typical examples of lunar surface features at high resolution.

A study of lunar meteoroid impacts based on calculations using the known meteoroid flux at earth resulted in a determination of impacts as a function of lunar longitude.(33) It was shown that on the average the leading (western)

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(30) Characteristics of Lunar Surface Experiments for Apollo Missions 16-19, Memorandum for File, J. W. Head, M. T. Yates, June 2, 1970.

(31) The Shape of a Lunar Crater Ray, Memorandum for File, P. Gunther, D. B. James, June 30, 1970.

(32) The Moon as Viewed by Lunar Orbiter, NASA SP-200, U. S. Government Printing Office, Washington, D. C., F. El-Baz (Bellcomm), L. J. Kosofsky (NASA).

(33) Numerical Calculation of Meteoroid Impacts on the Moon, TM-70-2013-3, L. P. Gieseler, April 23, 1970.

hemisphere of the moon receives more impacts than the trailing hemisphere. At 90° west longitude the excess is about 8% over the average.

Traverse Planning

A study of scientific activities associated with traverse stations on J-missions was completed in an attempt to define realistic estimates for mission planning.[34]

In cooperation with Field Geology Experiment Principal Investigator, material relating to possible walking missions to Marius Hills and Littrow was presented to a Marius Hills traverse planning group meeting in Flagstaff, Arizona. A similar study of possible traverses at Littrow was presented to the GLEP.

Orbital Science

Bellcomm participated as a member of the Lunar Sounder Ad Hoc Working Group, which is attempting to combine the Sounding Radar and EM Sounder Experiments.

The attitude dynamics of the Particles and Fields Subsatellite are being investigated to verify that the spin axis can be maintained within the desired 32° of the normal to the ecliptic plane. Sequential estimation methods are being implemented to determine the feasibility of using sun sensor data alone to estimate spin axis orientation within the desired 1° uncertainty.

A study was performed to determine what orbital instruments in the Apollo 16 payload could acquire useful scientific data in an alternate earth orbital mode.[35] It was found that camera characteristics favored an altitude of approximately 270 nautical miles and that significant data could be obtained from several of the experiments. The results of this study were presented to the Manned Spacecraft Center on April 30, 1970.

The orbital science experiments for monitoring lunar surface x-ray and γ-ray emission on Apollo 16 and 17 can also provide galactic x-ray and γ-ray astronomy data which may be of scientific interest. A study was performed to determine regions of scientific interest on the celestial sphere and to recommend

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(34) J-Mission Traverse Planning: The Implications of Apollo 13 Traverse Scientific Activities, Memorandum for File, J. W. Head, April 2, 1970.

(35) Operation of the Apollo 16 Orbital Experiments in an Alternate Earth Orbital Mode, Memorandum for File, W. L. Piotrowski, June 22, 1970.

procedures for the operation of these experiments during the transearth phase of the mission.[36]

Orbital Photography

A study was completed on the feasibility of using fine-grain Type SO-349 film in the Apollo Lunar Topographic Camera rather than the relatively faster (and coarser-grained) Type 3400 currently used for Apollo lunar orbital photography.[37] The results show a resolution improvement of more than 25% if high enough shutter speeds can be used.

A study was completed on the feasibility of using a Questar miniature astronomical telescope for lunar orbital spot photography.[38] Although the narrow field-of-view ($\sim 1.8°$) makes photography of specific points difficult due to pointing problems, the study concluded that photography of the lunar surface using the Questar is feasible under limited conditions.

As a participant in the Apollo Orbital Science Photographic Team, Bellcomm recommended a Variable Setting Intervalometer for the Hasselblad camera to achieve the objectives of Apollo photography, and a "latch-on" viewfinder for the Hasselblad camera to aid in aiming at the photographic targets. An analysis was performed on the contractor's film recommendation for the Metric Camera with a conclusion that either the criteria for film selection are incorrect or that the variation in lunar topography has been overemphasized.

Further study was made of ground-based photography of liquid oxygen released by the S-IVB on the Apollo 8 mission.[39] The parameters of a simple collisionless model for the expansion were obtained from reduction of the photometric data. The particles which are responsible for the scattering have a bulk velocity of 1.4×10^4 cm/sec and a thermal velocity of 0.3×10^4 cm/sec. The lower limit to the radius of the scatterers is one micron.

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(36) Operation of Gamma-Ray Spectrometer and X-Ray Fluorescence CSM Orbital Science Experiments on the Transearth Portion of Apollo 16 and 17, Memorandum for File, F. F. Tomblin, April 30, 1970.

(37) Lunar Topographic Camera Film Selection, Memorandum for File, H. W. Radin, May 27, 1970.

(38) Questar - Feasibility for Apollo Orbital Photography, Memorandum for File, H. W. Radin, June 19, 1970.

(39) A Physical Model of Apollo Oxygen Releases, TM-70-1011-3, A. C. Buffalano, April 29, 1970.

SKYLAB SYSTEMS ENGINEERING

Weight Reporting

Skylab I Weight and Performance reports for the months of April, May, and June were prepared, summarized for the Skylab Program Director and issued.

Skylab Program Specification

A major revision of the Program Specification resulting from the change from the "wet" to "dry" Orbital Workshop was approved by the Level I Configuration Control Board and distributed. Control weights and launch vehicle performance specifications were also approved and distributed. Requirements for experiments M151, M415, M479, M487, M509, S009, S019, S020, S073, S150, S190, S191, S192, S193, T013, T025, and T027 were prepared and distributed for comment.

Mission Sequence

Planned in-flight activities for Skylab astronauts have in the past been based on an 11-1/2 hour workday, seven days per week. The effect of limiting scheduled work periods to ten hours per day, six days per week was reviewed for the Skylab Program Director. Descriptions were given of: (1) the available time vs. the required time based on current planning, (2) timelines for typical in-flight workdays, and (3) present allocations of time for medical, Apollo Telescope Mount (ATM), and other experiments. Reductions in scheduled activities on the first two manned missions were shown to be necessary since time available for experiments would be 21% less than in current flight plans. A set of ground rules was proposed that would provide 1-1/2 hours of free time for each man on workdays and eight hours of free time every seventh day. It was noted that since significant portions of crew time for experiments are unsubstantiated estimates, experiment operating times based on simulation studies are needed for more realistic flight planning.

An operational priority system for Skylab experiments was proposed as a means of choosing among scheduling alternatives commonly encountered in the preparation of crew timelines.[40] Individual experiment tasks were assigned numerical values of relative operational importance, enabling groups of experiments to be selected for scheduling either by maximizing the combined operational value in a given region of mission time or by maximizing the value of experiments that would be accomplished in the event of an early mission

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(40) Operational Priorities for Skylab In-Flight Experiments, Memorandum for File, D. J. Belz, April 6, 1970.

termination. The proposed system was shown to provide more control over scheduling decisions than one based on simple rank-ordering of tasks, while avoiding the complexity inherent in the enumeration of scheduling alternatives prior to selecting tasks for inclusion in a timeline.

Preliminary in-flight scheduling requirements for Skylab experiments were translated into a format suitable for input to the Automated Task Scheduler (ATS) Program.[41] This data base has been constructed to explore the capability of ATS to generate prototype crew and equipment timelines for the first Skylab mission. Types of requirements presently incorporated include minimum and desired numbers of task repetitions, crew-time requirements, constraints relating tasks within the data base, constraints relative to the occurrence of spacecraft day/night cycles, and requirements for the availability of major items of on-board equipment. It was pointed out that since scheduling requirements differ among Skylab missions, separate data bases will be required for the two fifty-six day Skylab flights.

Flight Mechanics

From presently available information on the distribution of tentative Skylab earth resources ground truth sites, the majority are found to be concentrated in three climatological regions of the United States. Cloud coverage data for these three regions was assembled into a form which makes it possible to predict the effect of cloud coverage on earth resources photography.[42] The cloud coverage data can be combined with trajectory and lighting data to assess a potential Skylab launch date in terms of the expected return from the earth resources experiments.

The currently planned Skylab rendezvous profile was examined to determine the amount of tracking coverage available using the VHF ranging system.[43] The 327 nm maximum range of the system is the limiting factor; the 1900 ft/sec maximum range rate constraint is not exceeded while the vehicles are within that range. In some cases, tracking coverage is available prior to the second phasing maneuver for rendezvous. Coverage is available prior to the Corrective Combination maneuver (NCC) in all cases.

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(41) Status Report on Experiment Descriptions for the Automated Task Scheduler (ATS) Program, Memorandum for File, B. H. Crane, June 30, 1970.

(42) Cloud Cover Statistics for Tentative Skylab Earth Resources Sites; Interim Memorandum, Memorandum for File, E. W. Radany, June 29, 1970.

(43) Investigation of the Skylab Rendezvous Profile with Consideration to the VHF Tracking Coverage, Memorandum for File, C. O. Guffee, R. C. Purkey, April 23, 1970.

Skylab System Configuration

A recently imposed requirement to lower the CO_2 level in the Skylab has led to the addition of a second operating molecular sieve in the Airlock Module and a 50% increase in the flow rate through each sieve. Because the sieve absorbs water as well as CO_2, the humidity level is now far below the minimum requirement.(44) Possible methods of raising the humidity level would be either the addition of a separate humidifier or the addition of a silica-gel watersave bed that can be desorbed by dry air leaving the molecular sieves. Both of these methods add weight and require additional electrical power. An expendable lithium hydroxide system would maintain proper CO_2 and humidity levels, would weigh less, and would use less power than either system that retains the molecular sieves, but would require allocation of 50 cubic feet of internal volume for stowage of the LiOH canisters.(45)

Because of the Apollo 13 cryogenic tank failure, two alternate electrical power and oxygen storage systems were examined for the Skylab CSM.(46) Both systems use LM descent stage gaseous oxygen tanks in place of the Apollo Block II cryogenic tanks. One system uses fuel cells to provide electrical power; the other uses batteries. Based on weight and volume criteria, both of the alternate systems are capable of satisfying Skylab CSM requirements.

Attitude Control Studies

During the quarter, MSFC initiated documentation of the software design for the Skylab I Attitude and Pointing Control System (APCS) by the issuing of the Apollo Telescope Mount Digital Computer (ATMDC) Interface Program Requirements Document (IPRD). In order to validate the software design, work has begun at Bellcomm to develop an in-depth simulation of the APCS, which will include all attitude hold and maneuvering modes, simultaneous operation of the control moment gyroscopes (CMGs) and thruster attitude control system (TACS), and Skylab flexible body dynamics. This simulation will include nominal and backup modes of operation for both manned and unmanned phases of the mission.

In connection with the initial review of the IPRD, two memoranda were written. The first presented a precise statement of the properties of the mathematical relationships needed for evaluating calculations used to determine

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(44) The Skylab Humidity Problem and Several Possible Solutions, Memorandum for File, J. J. Sakolosky, June 15, 1970.

(45) Status of Skylab CO_2 Removal System, Memorandum for File, W. W. Hough, June 30, 1970.

(46) Alternate Electrical Power and Oxygen Storage Systems for the Skylab CSM, Memorandum for File, J. J. Sakolosky, May 28, 1970.

workshop attitude.[47] The second presented an analytical development of the CMG rotation law, previously developed by MSFC on geometrical arguments alone.[48] The analytic development revealed that certain simplifications in the rotation law, not apparent from the geometry, were possible.

Stellar Astronomy

In the last quarterly report a survey was reported on methods of solving the matrix Riccati equation in order to determine telescope structural response to random crew motion. The survey revealed that the available methods had computational shortcomings when applied to the large linear systems that describe lightly damped structures. A new method was developed that overcame these shortcomings.[49] This method was programmed as a subroutine called MTXEQN, and evaluated for a lightly damped structure excited by white noise. It was shown that accurate solutions of the matrix Riccati equation can be obtained for systems of up to 146 state variables, which permits a reasonable description of telescope or vehicle structures. The latter vehicle application should be useful for evaluating the performance of hard mounted Skylab experiments used with the scientific airlock.

Thermal Control System Studies

A computer thermal model of the Skylab Orbital Workshop being used by MSFC was obtained and is now operational. This program is being modified to reflect recent spacecraft configuration changes and to permit it to accept transient environmental heat loads rather than orbit averaged heat loads. The status of the current thermal model and some of the changes was reported.[50]

A concept for controlling heat transfer was disclosed.[51] High performance, multi-layer thermal insulations used in Apollo and Skylab spacecraft

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(47) Some Properties of Quaternions Related to Euler's Theorem, Memorandum for File, B. D. Elrod, June 26, 1970.

(48) Analytical Development of the Skylab CMG Rotation Law, Memorandum for File, J. Kranton, June 29, 1970.

(49) Evaluation of Routines for Numerical Solution of the Matrix Equation $AX+XA^T+B=0$, Memorandum for File, P. G. Smith, P. R. Dowling, June 25, 1970.

(50) Skylab Orbital Workshop Thermal Model, Memorandum for File, D. P. Woodard, A. W. Zachar, June 30, 1970.

(51) Means for Controlling Heat Transfer between Adjacent Surfaces or Bodies, Record of Invention disclosed to NASA, Reportable Item No. 68 under NASW-417, D. P. Woodard, May 18, 1970.

attain very low thermal conductivity values when evacuated. Changes in conductivity of several orders of magnitude can be achieved by varying the interlayer gas pressure. The gas pressure-thermal conductivity characteristics can provide a controllable heat leak path between adjacent surfaces or bodies. This is particularly useful for spacecraft applications where it is desired to transfer heat from the inside to the outside during periods of high internal heat production, and to conserve available internal heat during periods of low internal heat production.

Structures and Dynamics

A rigid body launch vehicle simulation to determine vehicle loads for the SL-2 configuration during launch was completed.(52) The responses of the vehicle in the pitch plane due to the control system, winds, and engine thrust are computed for the first 110 seconds of flight time. The results are consistent with earlier studies of Apollo by MSC and MSFC.

Experiments

An analysis of the experiment requirements for the Sleep Monitoring Experiment, M133, led to the conclusion that the experiment hardware could be simplified without compromising the basic experiment objectives. The simplification consisted of eliminating the on-board analyzer and telemetry interface while retaining on-board recording of data for post-flight analysis. This recommendation was approved at the Manned Space Flight Experiments Board meeting in June.

Skylab B Studies

An artificial gravity experiment is being considered for a second series of Skylab missions. Artificial gravity would be obtained by spinning the vehicle about an axis through its mass center. To maximize solar array power output, it is desirable that the axis normal to the array be the spin axis and that it be pointed toward the sun. However, for passive stable rotation, the spin axis must be the axis of maximum moment of inertia. A study of the rigid body dynamics of several configurations was performed.(53) They differed in the degree of alignment between the axis of maximum moment of inertia and the normal to the solar array. A configuration that employs ballast masses on

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(52) Launch Vehicle Flight Simulation - Rigid Body Dynamics, Memorandum for File, R. E. Hunter, June 16, 1970.

(53) Influence of Vehicle Dynamics on the Artificial Gravity Experiment on the Second Saturn Workshop, TM-70-1022-5, L. E. Voelker, April 17, 1970.

deployable booms 40 to 100 feet in length showed good dynamic behavior. This configuration is particularly attractive because the rest of the vehicle may be kept very similar to Skylab A.

Flexible body dynamics of a vehicle employing two 100 foot booms with 320 pound tip masses were simulated. It was shown that large boom deflections, leading to structural failures, can occur. Structural stability of ballast booms was therefore investigated on a theoretical basis.(54) For the Skylab configuration studied, steady rotation imposes no boom stiffness requirements when the spin axis and the normal to the solar array are within 5°, and this degree of alignment can be achieved with the ballast. Cases of non-steady rotation, including spin-up and wobble, do impose stiffness requirements and are a subject for future study.

After steady rotation has been achieved, gravity gradient torque and the yearly motion of the earth around the sun cause the Skylab spin axis to deviate from the sun line, and, if left uncorrected, the solar array power output would fall. The spin and sun vectors can be held aligned using the CSM reaction control system. The amount of RCS fuel required each day was calculated as a function of the direction of spin and the sun line-orbit plane angle, β.(55) The spin direction can be chosen to minimize fuel requirements, as the β angle history during the experiment will be known beforehand.

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(54) Deflection of Flexible Ballast Beams on a Spinning Spacecraft, TM-70-1022-11, R. J. Ravera, June 24, 1970.

(55) Estimate of Daily Fuel Required to Control Gravity Gradient and Solar Precession during an Artificial G Experiment, Memorandum for File, R. J. Ravera, W. W. Hough, June 15, 1970.

MISSION OPERATIONS STUDIES

A study was made of the support which can be provided for Skylab missions using a communications network with fewer stations than the current Apollo Manned Space Flight Network (MSFN).[56] It was shown that the Texas, Canary Island, and Guam stations contribute the least to Skylab mission coverage in terms of number of contacts, total contact time, and gap-filling capability. Elimination of some combination of these stations appears acceptable. A similar study was made of the support which can be provided for Skylab missions in combination with lunar missions which include lunar orbital and lunar surface science experiments. It was concluded that a network which is acceptable for support of the Skylab mission alone would also be acceptable for support of the combined programs.[57]

During the first hour of the Skylab SL-1 mission, certain mission-critical events (such as jettison of the payload shroud and deployment of solar arrays) are scheduled to take place when no MSFN coverage is available. Methods for providing coverage of these events were studied including (1) use of Apollo Range Instrumentation Aircraft (ARIA), and (2) storage of the data on board the Skylab Workshop for later dump to an MSFN station.[58]

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(56) Effect of Manned Space Flight Network Reduction on Skylab Support, Memorandum for File, J. P. Maloy, May 22, 1970.

(57) Combined Skylab and Lunar Support With a Reduced Manned Space Flight Network, Memorandum for File, J. E. Johnson, May 22, 1970.

(58) Use of ARIA for Support of Skylab A, Memorandum for File, A. G. Weygand, June 30, 1970.

SPECIAL TASK ENGINEERING STUDIES

Analysis of Haze Effects on Martian Surface Imagery

Task Order No. 35

In support of the Mariner Mars '71 mission planning effort, studies have been made of multiple scattering in planetary atmospheres. An iterative technique has been developed for computing the contribution of multiple scattering to observed atmospheric brightness for both spherical and planar geometries.(59) In the latter case a method developed by Chandrasekhar provides exact calculations with which the computer technique may be compared. An agreement to better than 0.5% was indicated. Use of the technique will improve the accuracy of the analysis of atmospheric brightness data provided by photography of the limb of Mars.

Five potential atmospheric science experiments for the Mariner Mars '71 mission were described.(60) These are (1) study of the thick haze that was suggested by the Mariner IV data; (2) study of thin haze seen in the data from Mariners 6 and 7; (3) determination of the atmospheric density profile of Mars through analysis of Rayleigh scattering; (4) measurement of the elevation profile of the planet by comparison of the atmosphere density at various places; and (5) monitoring of the camera performance by repeated photography of the atmospheric brightness above a specified region. The thick haze study was assigned low priority in mission planning because of the lack of evidence for such a haze in the Mariners 6 and 7 data.

Bellcomm participated in the preparation of a paper published by the Television Team of the Mariner Mars '71 mission. The paper describes the organization of the Television Team, the television cameras to be carried by the spacecraft, and the various investigations to be carried out during the mission.(61)

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(59) Multiple Scattering Calculation for Planetary Atmospheres, TM-70-1014-2, E. N. Shipley, May 15, 1970.

(60) Atmospheric Science Experiments for Mariner Mars '71, Memorandum for File, E. N. Shipley, June 24, 1970.

(61) Television Experiment for Mariner Mars 1971, Paper published in "Icarus," Vol. 12, No. 1, January 1970.

Manned Space Flight Program Planning

Studies were conducted to support NASA/MT Manned Space Flight program planning activities. Payloads for the manned program were analyzed, alternative Space Shuttle concepts identified, issues concerned with a large lift capability discussed, and design considerations for the Space Tug, Space Station, and Cislunar Shuttle examined. Alternative programs were developed for post-Apollo lunar exploration, and various manned missions were identified for the period between Skylab and Space Shuttle/Space Station availability.

The integrated space program corresponding generally to the maximum program (Option I) in the President's Space Task Group report was used to derive long-range traffic models for earth orbital operations, lunar exploration, and manned planetary missions.(62) It was concluded that cislunar flight activity will achieve a fixed level in 1982 with an annual traffic of 90-95 Space Shuttle flights and two INT-21 launches. Additional annual traffic to support manned planetary operations will not exceed 24 Space Shuttle flights and four INT-21 launches.

An analysis of candidate space transportation systems for the 1970s and 1980s was initiated, based on the premise that the Space Shuttle must be viewed as part of the total transportation system rather than as an isolated element.(63) Preliminary results indicate that some shuttle configuration concepts with potential advantages over the two-stage fully recoverable lifting body shuttle should be examined further.

It was shown that a Shuttle Orbiter can be sized for high energy missions involving transportation from low earth orbit to synchronous equatorial or lunar orbit and return.(64) Aerodynamic braking on return provides a performance advantage over propulsive orbit-to-orbit vehicles such as the Space Tug. To improve mass fraction and reduce total launched weight, a vertical landing, ballistic configuration is preferred. Such vehicles may also be useful to shuttle from lunar orbit to the lunar surface, thereby offering potential for a complete manned cislunar capability.

Two-stage ballistic booster systems were analyzed to evaluate the feasibility of returning the first stage to the launch site with a post-separation

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(62) Integrated Manned Space Flight Program Traffic Model, Memorandum for File, E. M. Grenning, June 4, 1970.

(63) Space Transportation System Analysis, TM-70-1012-2, E. D. Marion, May 12, 1970.

(64) A Cislunar Shuttle, Memorandum for File, G. T. Orrok, March 23, 1970.

impulsive maneuver.[65] Although certain operational problems, such as the requirements for rapid engine restart, flight at high angles of attack, and rapid vehicle reorientation warrant further study, the maneuver appears to be feasible and is attractive from the standpoint of recovery operations and vehicle sizing.

A performance analysis was carried out to determine if an expendable cyrogenic stage which is suitable for use as an upper stage with the Space Shuttle booster would also be of an appropriate size for use as a booster stage with the S-IVB for placing large payloads into orbit.[66] In an evolutionary program the latter configuration could serve as an interim launch vehicle in lieu of Saturn V while later in the program large payload capability would be provided by the Shuttle booster plus the dual-purpose stage. It was found that if the 25,000 pound payload Shuttle booster is capable of carrying an 800,000 pound expendable cryogenic stage, it could place a 170,000 pound payload in earth orbit. This same stage could place up to 95,000 pounds in earth orbit when used with a modified S-IVB second stage.

An evaluation of the extent to which the Space Shuttle could support presently planned unmanned earth orbital, planetary and interplanetary missions was conducted.[67] The results show that a Space Shuttle with a 25,000 pound nominal payload capability could insert all low altitude and low inclination astronomy payloads directly and could deliver the payload plus the necessary injection stage for all other missions. With a 50,000 pound nominal payload capability, the Space Shuttle could also accommodate direct orbital insertion of all the low altitude, high inclination earth observation payloads. The space physics, high altitude earth observation, and communications satellite payloads would require injection stages.

Possible lunar exploration activities were described for the decade after Apollo.[68] A range of goals, including exploration, scientific investigation, and exploitation was defined and compared with a corresponding range of systems. In order of increasing effort, the potential activities are: (1) groundbased analysis of existing data; (2) orbital survey missions to complete global photographic coverage at intermediate resolution (30-90 meters) and at low and high sun angles; (3) high resolution orbital surveys to select sites for additional surface missions considering scientific interest and landing safety; (4) a limited

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(65) Launch Site Recovery of Ballistic Boosters, Memorandum for File, E. D. Marion, June 9, 1970.

(66) Potential of Dual Purpose Expendable Cryogenic Stage as Replacement of the Saturn V, Memorandum for File, J. J. Schoch, June 10, 1970.

(67) Estimated Space Shuttle Capability in Support of Unmanned Payloads, Memorandum for File, D. E. Cassidy, April 21, 1970.

(68) Post Apollo Lunar Exploration, Memorandum for File, R. N. Kostoff, G. T. Orrok, S. Shapiro, W. R. Sill, A. R. Vernon, June 17, 1970.

number of surface missions consistent with unmanned point landers (Surveyor-Viking) or with Apollo J-missions to complete the sampling of major nearside terrain types, and possibly, additional sites on the far side; and (5) extended capability surface missions to attack particular scientific problems.

The fourth category was studied further. Six classes of lunar missions that use Viking spacecraft in the post-Apollo period were described.[69] The requirement for minimum Viking modifications is met by excluding new instrument developments and by limiting changes in the propulsive system to those necessitated by descent to the moon. The missions include orbital missions using the Viking orbiter alone, as well as combined orbiter-lander operations. The former could meet the scientific objective of complete photographic coverage of the moon at high resolution (approximately 10 meters) or fulfill the operational need for partial coverage at even higher resolution (approximately 2 meters) desired for landing site survey. In the more ambitious scientific missions to regions near the poles, on the limbs, and on the far side, the primary experimental tasks would be performed on a suitably adapted lander, whereas the orbiter would function chiefly as a data relay. For the observation of transient events, the experimental payloads of both the orbiter and lander are essential.

Manned Space Flight Experiment Program Studies

An analysis was made of the needs for flight performance data on man-operated systems.[70] The best balance of crew safety and mission objectives results from combining real-task performance measures, obtained in manned flight experiments and operational tasks, with test-task experimental data and biomedical indices. Specific parameters were identified to provide a framework for performance evaluation in terms of task time, accuracy, and costs in systems expendables. The feasibility of integrating these data into existing planning, documentation and review procedures was identified.

Urine void frequency and volume data taken from the McDonnell Douglas Astronautics Company's 60-day manned simulator study and from Gemini 7 mission were examined.[71] It was determined that an 80 ml sample would have to be taken from each void to assure subsequent reconstitution of a 120 ml sample that was representative of the daily urine output as required by Skylab

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(69) Viking Spacecraft for Lunar Exploration, Memorandum for File, R. N. Kostoff, M. Liwshitz, S. Shapiro, W. R. Sill, A. C. E. Sinclair, June 30, 1970.

(70) Defining and Reporting the Inflight Performance of Man-Operated Systems, Memorandum for File, B. A. Gropper, May 22, 1970.

(71) Urine Output Variables and M071/73 Sampling Requirements, Memorandum for File, L. D. Sortland, June 26, 1970.

medical experiments. An alternate sampling scheme based on obtaining a 120 ml sample directly from a daily pooled collection of urine, has been selected for implementation in the Skylab Program.

A chamber contained within an orbiting spacecraft and having the capability of exhausting gas to the low pressure vehicle wake may be desirable for on-board high-vacuum experiments. The theoretical time necessary to pump this chamber from near-atmospheric pressure to 10^{-13} millimeters of mercury was calculated.[72] Depending on the chamber exit dimensions, this time ranges from a few seconds to a few minutes. It is considerably less than system outgassing, baking, and cooling times and is therefore not a controlling factor in determining system feasibility.

Scientific Studies

Theories and data correlating visual markings with surface relief of Mars were reviewed.[73] A long-standing opinion held that the dark areas are lowlands. In recent years, there has been increasing indirect evidence indicating that the dark areas are elevated above the rest of the surface. Direct evidence of surface relief on Mars has been obtained through radar ranging measurements and through CO_2 spectroscopic experiments. These data indicate that there is surface relief of 10 kilometers but that there is no correlation between surface relief and visual markings. However, it is possible to interpret the radar data as indicating that dark areas are at least locally lower than surrounding regions.

A tradeoff study showed that the level of uncertainty in the knowledge of the Martian atmosphere can have a marked effect on design of landed payloads.[74] Taking Viking as an example, if the minimum Martian atmosphere were known more accurately, the Viking aeroshell diameter could be reduced since the decelerating drag force is proportional to the atmospheric density and the aeroshell size. The corresponding saving in aeroshell weight could be translated into an increase in the scientific payload. For the presently proposed weight model, a 1 percent reduction in aeroshell weight yields a 4 percent increase in scientific payload weight. Some reasonable estimates of the atmosphere indicate that the landed instrument weight could be nearly doubled.

A detailed analysis of aborts from the outbound leg of a low-energy mission to Mars in 1981 revealed three phases: (1) a brief opportunity immediately

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(72) Use of Satellite Wake Region as a Vacuum Pump, Memorandum for File, R. N. Kostoff, April 7, 1970.

(73) Surface Relief on Mars, Memorandum for File, E. N. Shipley, June 22, 1970.

(74) Sensitivity of the Viking Aeroshell and Scientific Payload to Knowledge of the Martian Atmosphere, Memorandum for File, J. L. Blank, May 22, 1970.

after launch in which economical aborts may be accomplished with short return durations and low entry velocities, (2) an extended period in which only long returns are available, and (3) the remaining leg duration in which moderately long returns are available but which result in high Earth return velocities.[75] The results of other analysis involving a variety of missions to both Mars and Venus correlate with these results.

An externally mounted system of pressure gages that is capable of locating spacecraft leaks of approximately 40 gm per day was devised.[76] The system is applicable only to interplanetary vehicles, which operate where the external ambient pressure is effectively zero. For an earth orbital vehicle, the system is reasonable only for vehicle wake region measurements.

Photographic observations of Earth sites from orbit must be made with the target site suitably illuminated. The ground illumination (or solar elevation angle) depends upon local mean time and date, and the times of sightings depend on the orbital motion of the satellite with respect to Earth. Given the altitude and inclination of a circular orbit, a method was devised for determining the Sun's elevation when sightings occur.[77] Conversely, suitable orbital parameters can be determined for specific illumination requirements. Sun-synchronous orbits, frequently proposed for observations at constant solar elevation, are the most suitable only for missions longer than one year. For short missions, such as those planned for the Space Shuttle, constant illumination angles can be attained with higher accuracy using non-synchronous orbits.

Calculation of some of the physically interesting properties of particle distributions led to solution of the functional-differential equation: $x\psi'(x) + \alpha\lambda^{\alpha}\psi(\lambda x) = 0$. This equation arises in the theory of collisions of astronomic particles. An explicit family of solutions was obtained, and for the parameter λ lying in the range of interest, this family was shown to be the only family satisfying certain desired properties.[78]

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(75) Abort From Mars and Venus Missions, Memorandum for File, A. A. VanderVeen, April 15, 1970.

(76) Automated Leak-Detection System for Manned Interplanetary Spacecraft, Memorandum for File, R. N. Kostoff, May 5, 1970.

(77) Illumination Conditions for Satellite Observations, Memorandum for File, S. Shapiro, June 29, 1970.

(78) On Solutions to a Functional-Differential Equation Arising in the Theory of Particle Collisions, S. C. Chu, TM-70-1033-6, May 1, 1970.

Technological Studies

Plated-wire memory technology was reviewed to assess its potential for use in spaceborne main memories and in spaceborne mass memories of up to 10^8 bits.(79) The non-volatility of plated-wire memories, when considered along with their other desirable characteristics and with the fact that they are semi-batch fabricated, makes them an attractive choice for future spaceborne applications.

The technology status of advanced composite (fiber reinforced) materials and their structural application to advanced manned space vehicles, particularly the Space Shuttle, was examined.(80,81) It was found that advanced composites are attractive for primary structures because of their high specific tensile strength, high specific modulus and excellent fatigue strength. These properties could lead to potential weight savings and increased cost-effectiveness. Among the advanced composites developed, boron/epoxy, graphite/epoxy and boron/aluminum are generally considered to be candidates for near-term applications. The material properties of boron/epoxy are well-characterized and a significant amount of engineering experience has been accumulated. Graphite/epoxy is a newer material which has become increasingly important; it is easy to fabricate, and has potential for further improvement of mechanical properties. Boron/aluminum is behind the epoxy matrix composites in terms of applications experience, design data and fabrication techniques.

A preliminary assessment was made of the risk of meteoroid damage to a coated columbium radiative heat shield for a Space Shuttle.(82) Radiative heat shields representative of current preliminary design will afford a probability no greater than 0.9 that no puncture will occur in a single 3-day mission. Achievement of 0.999 no-puncture probability would incur large weight penalties. With respect to the risk of pitting, it is estimated that about 20 pits per mission will occur in a typical 3000 square foot heat shield, damaging a coating surface area of 0.004 square inches. Acceptable values of damaged coating area remain to be established. Assessment of the risk of critical meteoroid damage requires further laboratory testing to determine the effects of high speed hot-gas impingement, similar to the reentry environment, against punctured or pitted specimens.

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(79) The Plated-Wire Memory and Its Potential for Aerospace Applications, Memorandum for File, B. W. Kim, May 20, 1970.

(80) Advanced Composites for Aerospace Structures, Memorandum for File, A. S. Kiersarsky, C. C. Ong, May 19, 1970.

(81) Air Force Structural Design Guide for Advanced Composite Applications, Memorandum for File, C. C. Ong, April 3, 1970.

(82) The Effect of the Meteoroid Environment on a Coated Columbium Radiative Heat Shield for a Space Shuttle, TM-70-1012-1, J. C. Burford, C. E. Johnson, C. C. Ong, April 17, 1970.

Analysis of on-board checkout capability for eventual use in manned space missions shows that such capability would also offer a number of advantages for Space Station use. It would provide continuous monitoring of on-board systems, less dependence on communication systems, faster response, less overall data handling, and potential cost savings.[83]

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(83) Space - vs - Ground Tradeoffs for Checkout Functions in a Space Station; an Ambiguous Situation, Memorandum for File, J. R. Birkemeier, April 10, 1970.

ENGINEERING SUPPORT

Computing Facility

The UNIVAC 1108 computer operations were continued under the EXEC 8 multi-programming system. During the period from April 1 to June 30, NASA Headquarter usage of the UNIVAC 1108 computer was 18,279 charge units. Total usage of the computer during the quarter was 799,193 charge units.

LIST OF REPORTS AND MEMORANDA

(List in Order of Report Date)

This index includes technical reports and memoranda reported during this period covering particular technical studies.

The memoranda were intended for internal use. Thus, they do not necessarily represent the considered judgment of Bellcomm which is reflected in the published Bellcomm Technical Reports.

TITLE	DATE
Television Experiment for Mariner Mars 1971 Paper published in "Icarus," Vol. 12, No. 1	January 1970
A Cislunar Shuttle, Memorandum for File, G. T. Orrok	March 23, 1970
Projected Activities at Science Stations for J-Mission Traverse Planning, Memorandum for File, P. Benjamin	April 1, 1970
J-Mission Traverse Planning: The Implications of Apollo 13 Traverse Scientific Activities, Memorandum for File, J. W. Head	April 2, 1970
Air Force Structural Design Guide for Advanced Composite Applications, Memorandum for File, C. C. Ong	April 3, 1970
An Analysis of the Capability to Perform the Apollo 13 Fra Mauro Traverses, Memorandum for File, T. A. Bottomley	April 6, 1970
Operational Priorities for Skylab In-Flight Experiments, Memorandum for File, D. J. Belz	April 6, 1970
Statistical Analysis of Non-stationary Structural Response Under Feedback Conditions, TM-70-2031-2, I. Y. Bar-Itzhack, S. N. Hou	April 6, 1970
Revision of Operational Constraints for J-Mission Traverse Planning, Memorandum for File, P. Benjamin	April 7, 1970
Use of Satellite Wake Region as a Vacuum Pump, Memorandum for File, R. N. Kostoff	April 7, 1970

TITLE	DATE
Contour Spectrograms for POGO Analysis, Memorandum for File, A. T. Ackerman, L. A. Ferrara, J. J. O'Connor	April 10, 1970
Space - vs - Ground Tradeoffs for Checkout Functions in a Space Station; an Ambiguous Situation, Memorandum for File, J. R. Birkemeier	April 10, 1970
Apollo 12 - Landing Site 7 - Part 1; Geology of the Landing Site and Scientific Objectives, Memorandum for File, J. W. Head	April 13, 1970
Abort From Mars and Venus Missions, Memorandum for File, A. A. VanderVeen	April 15, 1970
Effect of Lunar Slopes on LM Guidance Perturbations Prior to High Gate, TM-70-1033-4, P. Gunther	April 16, 1970
Influence of Vehicle Dynamics on the Artificial Gravity Experiment on the Second Saturn Workshop, TM-70-1022-5, L. E. Voelker	April 17, 1970
The Effect of the Meteoroid Environment on a Coated Columbium Radiative Heat Shield for a Space Shuttle, TM-70-1012-1, J. C. Burford, C. E. Johnson, C. C. Ong	April 17, 1970
An Improved Determination of Optimal Moon-to-Earth Trajectories for BCMASP, Memorandum for File, M. R. Kerr, R. J. Stern	April 20, 1970
Estimated Space Shuttle Capability in Support of Unmanned Payloads, Memorandum for File, D. E. Cassidy	April 21, 1970
Investigation of the Skylab Rendezvous Profile with Consideration to the VHF Tracking Coverage, Memorandum for File, C. O. Guffee, R. C. Purkey	April 23, 1970
Numerical Calculation of Meteoroid Impacts on the Moon, TM-70-2013-3, L. P. Gieseler	April 23, 1970
A Physical Model of Apollo Oxygen Releases, TM-70-1011-3, A. C. Buffalano	April 29, 1970
Operation of Gamma-Ray Spectrometer and X-Ray Fluorescence CSM Orbital Science Experiments on the Transearth Portion of Apollo 16 and 17, Memorandum for File, F. F. Tomblin	April 30, 1970

TITLE	DATE
On Solutions to a Functional-Differential Equation Arising in the Theory of Particle Collisions, TM-70-1033-6, S. C. Chu	May 1, 1970
Automated Leak-Detection System for Manned Interplanetary Spacecraft, Memorandum for File, R. N. Kostoff,	May 5, 1970
Orbit Determination for Lunar Parking Orbits Using Time-Varying Orbital Elements, TR-70-310-2, M. V. Bullock, A. J. Ferrari	May 7, 1970
Space Transportation System Analysis, TM-70-1012-2, E. D. Marion	May 12, 1970
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